A Economic Load Dispatch Using Reactive Power Optimization Approach

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Abstract: **The prime focus was the concept economic load dispatch (ELD) is one of the main functions of modern energy management system, which determines the optimal real power setting of generating units with an objective to minimize total fuel cost of thermal plants.It is general fact that reactive power produced due to reactive components and loads connected to the network, is essential for transmission of active power through transmission and distribution power network.In current dynamic and automated environment, it was essential to analyze and check the dynamic assessment of reactive power of the network subject to pre and post fault conditions from interval to interval.**

In this paper, we present a novel approach for reactive power optimization (RPO) based on reactive power planning (RPP) that incorporates nonlinear combinatorial constrained problem in the field of power system analysis. RPP basically serves to determine the optimal setting and location of the power system network to satisfy few constraints focused on power flow equation and equipment operating limits. Reactive Power Planning (RPP) involves allocation and sizing of static reactive resources for normal operation of the power system. These are devices whose reactive capacity is fixed andinclude series and shunt capacitors, reactors etc. Additionally, dynamic resources are also used in case of contingency on components such as transformers, transmission lines and power plant units. The power system being a practical system has several constraints such as capacity limits of the resources, system voltage limits etc. The IEEE 14-bus network is used as the test network and the code developed using MATLAB for the RPP problem. Results obtained show a reduction in real and reactive losses and improvement in the voltage profile.

***Keywords**: Applied statistics, Power Electronics, Power System, Reactive power planning, soft computing techniques*

1. Introduction

Our technological world has become deeply dependent upon the continuous availability of electrical power. Commercial power literally enables today's modern world to function at its busy pace. Sophisticated technology has reached deeply into our homes and careers, and with the advent of e-commerce is continually changing the way we interact with the rest of world. Now-a-days several solid state power electronic devices are gaining importance as the enabling technology not only for integrating various systems into Grid but also for operation of conventional electrical machines. To identify the requirement and volume of the reactive power resources for normal operating conditions in various system constraints is a complex task.

Reactive power planning (RPP) estimation has evolved into significant research field within power electronics that encompasses the science of estimating the probable effort essential for developing a power system. Due to the dynamic nature of power electronic devices, the planning techniques focus on development and advancement involving applied mathematical tools, statistical based algorithms and constraints assumption. In practical this issues can be viewed as an optimization problem and power network structure is primary factor for righteous reactive power estimation function at any stage as there is significant lost and cost attached to power system network. We employ various factors such as selection, crossover and mutation with the aim of improving fitness of subsequent generations for survival. Most of these modern electronic devices are power electronic converter inverter based. The non-sinusoidal input line current drawn by these equipment's due to input line rectification generates current harmonics that causes severe problems. These include increased magnitudes of neutral currents in three-phase systems, overheating of transformers and induction motors. This creates the need for some kind of power conditioning. Hence, it became equally important to limit harmonic content of line currents drawn by electronic equipment connected to the electricity distribution networks. As the use of power electronic devices are increasing in our day to day life the power factor correction (PFC) has become a necessary feature of modern AC/DC power electronic appliances.

The focus is to investigate methods to improve EMI, improve efficiency and optimization using FACTS devices. Thus the overall objective of this work is to develop a method that reduce overall Voltage instability in weak system and improve performance of FACTS based PFC circuits. The complexity of interconnections and the size of the areas of electric power systems that are controlled in a coordinated way are rapidly increasing which led to the need of Automatic generation control (AGC). The generic function automatic generation control within a predefined control area depends on the following:

1. Economic dispatch and
2. Load frequency control

Economic Dispatch (ED) is defined as the process of allocating optimal power generation levels to each of the generating units in the station, so that the entire supply demand can be meet in a most economically manner. In case the load is fixed (i.e. static economic dispatch), the objective is to calculate, for a single period of time, the output power of every generating unit. Unfortunately the load of a power system is always changing, so the generators correspondingly respond i.e. with increase in the load the generator produces more power and vice-versa. This entails for optimal allocation of generators participation in sharing the load at the current interval of time to meet the forecasted load demand for the same interval. As per our definition, economic load dispatch is a means that allows the generators active and reactive powers to vary within a range to obtain the desired objectives of this research which are as follows

1. to minimize the generation cost,
2. to minimize the total power loss in the power system network,
3. to minimize the voltage (and/or current) deviations, and
4. to maximize the quality of the power supplied to the customers.

Over the past decades, extensive research on optimization models and algorithms for ELD problems have been explored and exploited. In addition to the traditional methods such as equal incremental method, dynamic programming (DP), Lagrangian relaxation method (LR), artificial intelligence methods such as genetic algorithm (GA) chaos optimization algorithm (COA), and particle swarm optimization (PSO)[63] have been successfully employed to solve the ELD problems. However, with the dramatic increase in the number of generating units, existing stochastic algorithms may result in the curse of dimensionality, and the difficulty of optimizing calculation redoubled as well as the consuming-time. There is considerable interest in merging or combining neural networks, fuzzy logic and genetic algorithm based systems into a functional system to overcome their individual weakness. This innovative idea of integration brings the low-level learning and computational power of neural network into fuzzy logic systems and merges the high level human-like thinking and reasoning of fuzzy logic systems into neural networks. Similarly integration with genetic algorithm results in solution optimization. Such synergism of integrating neural networks and these techniques into a functional system provides a new direction towards the realization of intelligent systems, which are unaffected by model complexities.

The present article proposes to work on soft computation based alternate solutions for optimal operation of power system as these methods are robust and computationally simple as compared to the classical methods. Reactive power Planning (RPP) is known to be a large-scale nonlinear combinatorial constrained problem in the field of power system analysis. RPP basically serves to determine the optimal setting of the power system network to satisfy few constraints discussed in the above section such as the power flow equation system security and equipment operating limits. Several researchers and power engineering experts have tried to solve and analyze RPP via optimization (i.e. Reactive Power Optimization) by developing various search strategies and frameworks as solving this problem has a drastic impact on the economic load dispatch. Due the important role of reactive power, it is necessary to plan on its availability and quantity in a power system. RPP refers to the proper sizing and location of reactive power resources for normal operating conditions and also in case of a contingency or disturbance within the power system. In the short-term, RPP is known as reactive power optimization (RPO) and its purpose in a power system is to identify the control variables that minimize a given objective function while satisfying the unit and system constraints. Scheduling of reactive power in an optimum manner reduces circulating VAR (volt ampere reactive), thereby promoting a uniform voltage profile which leads to appreciable power saving on account of reduced system losses.

In the long term RPP seeks to identify location and sizes of RP resources. This is done subject to various system constraints such as voltage limits and capacity of resources. Due to the load fluctuations in a power system, it is necessary to have compensators that that can inject or draw RP both continuously and instantaneously from the power system so as to balance between the RP at the sending end and that at the receiving end. The optimization problem will be formulated with constraints such as generator limits, power balance equation, ramp limits and prohibited zone etc. Different soft computing methods discussed above will be employed to solve the ELD problem with RPO assessment with diverse and conflicting constraints. Soft computing approaches are known to perform well under such uncertain conditions due to their simplicity and flexibility.

Suitable performance indices will be developed using soft computing techniques to effectively measure the severity of a contingency. Data will be generated using conventional techniques in wide range of system operating conditions by changing loads and generations at all nodes. The focus of the proposed research study will be to investigate the most appropriate and economical methodology to meet the committed load demand.

The conventional methods take long time in achieving the solution to optimization problems, preventing their use in real time. The proposed work will be helpful in real time application. In real time load dispatch, operator uses his judgment based on his experience to handle continuously changing situations. Proposed work based on soft computing approaches such as ANN, GA and their hybrid combinations will be suitable for real time applications. A salient feature of the proposed approach is that the solution time grows approximately linearly with problem size as compared to dynamic programming where the time increases geometrically with problem dimension.

Integration of soft computing techniques is expected to produce accurate results under uncertain and unpredictable operating conditions prevailing in practical power system. The results are expected to be useful to power utilities in their on-line contingency selection-ranking and reactive power dispatch at energy control centers. Dynamic ELD solution will be useful in the restructured environment where market is governed on the basis of spot prices. The main objective of this paper is to explain the impact of effective reactive power planning. Genetic algorithm is used as the optimization technique for this multi-objective problem. GA operators are to be understood in detail and used to write a program in MATLAB simulation software package to solve the RPP problem. The effectiveness of the GA is verified on an IEEE 14 bus system to give an optimal solution. The objectives can be thus stated as;

a) To understand the importance of the power electronic devices and analyze their corresponding functionalities within the boundaries of the power system network constraints.
b) To determine the location and size of RPC while minimizing cost, losses and maintaining voltage stability subject to the power system constraints.
c) To understand Genetic Algorithm and use it to find the optimal solution

The rest of the paper is organized with section 2 deals with detail background survey on the existing works with complete analysis on drawbacks and concepts employed. While section 3, discusses power electronic devices with their operations and schematics that are employed for enhancing and estimation of the proposed algorithm. Section 4 deals with the basic estimation algorithm based on GA with detail algorithm steps and complete architecture. Section 5 presents the simulation analysis of the IEEE 14-bus system under various conditions. Finally section 6, presents the conclusion and feature work.

2. Background

In past few decades, relatively very little head way was made within the field of power electronics engineering with prime focus on power optimization techniques, while the level and frequency associated with the power system network over runs were becoming vital and increasing exponentially to numerous large organizations. In later years, several organizations focused on the effective and efficient framework of Reactive Power Planning (RPP) and evolved into a lucrative and landmark project with reference to power system network development. Detailed literature survey on reactive power using conventional as well as different soft computing approaches is done and a brief review is presented here.

Economic load dispatch

Economic load dispatch (ELD) is one of the main functions of modern energy management system, which determines the optimal real power setting of generating units with an objective to minimize total fuel cost of thermal plants. Optimization is done by minimizing selected objective functions while maintaining an acceptable system performance in term of generator capability limits and output of the compensating devices. The objective functions, also known as cost functions may present economic costs, system security, or other objectives [1]. Many techniques such as the lambda iteration method, base point and participation method and dynamic programming method [2,3] have replaced obsolete techniques such as the best point loading and base load methods . All these methods consider ELD problem as a convex optimization problem and assume that the whole of unit operating range between minimum and maximum generation limit is available for operation.

Economic load dispatch problem has been solved by researchers using conventional as well as modern methods employing different objective functions. In practical systems, the operating range of all units is restricted by their ramp limits [4], and prohibited operating zone due to physical operational limitations. With advances in digital computing, a number of techniques have been developed for generation cost optimization. Although the most commonly used method in literature is the lambda iteration [5] due to its simplicity, its application to large scale model is not feasible due to oscillatory problems. Also, the constraint handling capability of the technique is questionable. Efficient dispatch schemes are still being developed to give minimum cost with least solution time. Various ANN based methods have been proposed for the ELD problem [6-12]. Application of Hopfield method [13], two phase neural network [14] and Radial basis function [15] can be found in literature. Methods based on GA [16], fuzzy logic [27], fuzzy GA combination [17, 18] and combination of GA with other methods [19] is also reported in literature. Paper [20] handles the multi objective ELD problem with particle swarm optimization technique.

Soft computing methods

Researchers worldwide are increasingly proposing soft computing methods as alternate approaches for solving power system optimization and other problems, as these methods are based on natural phenomena and hence are more robust and suitable for real world problems. They have parallel computation, fault tolerance and simple modeling techniques, which make them attractive for practical problems. Load shedding decisions based on fuzzy reasoning and neural classifications have been proposed to avoid voltage collapse [21]. Genetic algorithm based reactive power optimization has been employed to assess the impact of outages and to enhance voltage security margin by optimal dispatch of reactive sources [22,23]. The concept of fuzzy logic and artificial neural network, when integrated with genetic algorithm [22,23,24] results in models which can handle non-linearity and imprecision and produce flexible practical solutions.

Noteworthy contribution in the field of proposed work

Over the past few years, several approaches using soft computing techniques have been proposed for solving the on line ELD problems with environmental and security constraints. Multi layer Perceptron [14] and RBF based approaches are very fast because they map total demand with individual generations, for minimum operating cost. The main advantage with ANN based approaches lies in achieving accurate solutions without increasing computational complexity. A variety of Hop fields models [25] have been employed for solving ELD problems. Recently a two phase neural network (TPNN) [14] has been proposed which deals with all the constraints in real time and can be realized in hardware for faster operation. Walter and Sheble [16] proposed Genetic algorithm, as a tool for optimal generation scheduling incorporating the valve point loadings and demonstrated that this approach was many times faster that the dynamic programming approach. Later GA was proposed for ELD of generators having prohibited operating zones [26]. The network constraints have been included and effect of coding of variables on solution accuracy has been demonstrated. Paper [27] presents the solution of ELD problem with conflicting constraints of minimum fuel cost and minimum emission, employing fuzzy satisfaction maximizing approach. Recently a combination of GA with fuzzy logic [28], GA with tabu search [29] and particle swarm optimization has been proposed for the ELD problem. Reference [30] proposed a new fuzzy dynamic ELD model assuming uncertain cost coefficients, suitable for the day-ahead market. The problem is solved by a combination of GA and quasi-simplex technique.

Soft computing methods are extensively being proposed for ensuring secure operation of power system. Artificial neural networks [31-35], fuzzy logic [36] and fuzzy neural networks [37-40] have been proposed for static and dynamic security assessment and contingency ranking issues. Genetic algorithm based methods are proposed for reactive power optimization [42] and dispatch [41].

The biogeography based optimization (BBO) by modifying its migration models can make it more realistic. This BBO technique is then applied on simple economic load dispatch (ELD) problem and ELD with valve point effect to analyze the effect of different migration models.[43]The combination of particle swarm optimization (PSO) and biogeography-based optimization (BBO) algorithm to solve constrained economic load dispatch (ELD)[61] problems in power system, considering valve point nonlinearities of generators, prohibited operating zones, ramp rate and spinning reserve. PSO is a well popular and robust evolutionary algorithm for solving global optimization problems, whereas BBO is a relatively new biogeography inspired algorithm. The hybridization of PSO and BBO (HPSOBBO) is proposed to improve the convergence speed and solution quality. This method also produces stable convergence characteristic and avoids premature convergence. [44]

The economic load dispatch (ELD) plays an important role in power system operation and control. Different techniques have been used to solve these problems. Recently, the soft computing techniques have widely used in practical applications. Reference [45] gives the successful implementation of four evolutionary algorithms, namely particle swarm optimization (PSO), particle swarm optimization with constriction factor approach (PSOCF A), particle swarm optimization with inertia weight factor approach (PSOIWA) and particle swarm optimization with constriction factor and inertia weight factor approach (PSOCFIWA) algorithms are used to economic load dispatch problem. Here prohibited zone and ramp-rate limit constraints are considered to solve this problem. Power output of each generating unit and optimum fuel cost obtained using all four algorithms have been compared.

The optimization problem will be formulated with constraints such as generator limits, power balance equation, ramp limits and prohibited zone etc. Different soft computing methods discussed above will be employed to solve the ELD problem with RPO assessment with diverse and conflicting constraints. Soft computing approaches are known to perform well under such uncertain conditions due to their simplicity and flexibility.

Suitable performance indices will be developed using soft computing techniques to effectively measure the severity of a contingency. Data will be generated using conventional techniques in wide range of system operating conditions by changing loads and generations at all nodes. The focus of the proposed research study will be to investigate the most appropriate and economical methodology to meet the committed load demand. In this thesis, we focus of the planning of possible reactive power units locations so as to improve the overall power system network stability scenario.

2.1 **Reactive Power**

Reactive power (RP) is the imaginary component of complex power stored in form of magnetic and electric fields by inductors and capacitors respectively. RP is needed for transfer of real or useful power in an AC system to maintain voltage stability of the power system. Most loads in an AC power system are either inductive or capacitive in nature. This implies that the power in the system is complex power,

$$S = P + j * Q$$

Where, P is the real/active power component while Q is the imaginary or reactive power component. The active power is the useful power necessary to do work and is measured in Watts. The reactive power on the other hand alternates and is returned to the source. It is measured in VAR. It is stored in the form of electrical fields in capacitors or magnetic fields in inductors. It is useful in maintaining voltage levels stable and its absence may lead to voltage collapse partially or totally (blackout).It is general fact that reactive power (even though imaginary) produced due to reactive components and loads connected to the network, is essential for transmission of active power through transmission and distribution power network. However, the permissible level of reactive power in a system is commonly calculated based on power factor judged by the power network operator.

In current dynamic and automated environment, we found it was intriguing to analyze and check the feasibility of dynamic assessment of reactive power from interval to interval. The prime motivation for addressing this problem was that it is an important aspect in controlling the power system's operation and planning. Thus in this thesis, we present a Reactive Power Planning problem that will be formulated with constraints such as generator limits, power balance equation, ramp limits and prohibited zone etc.

Inequality Constraints:

1. **Voltage Constraints:**

$$\boldsymbol{V_{min}} \le \boldsymbol{V} \le \boldsymbol{V_{max}}$$

$$\boldsymbol{\delta_{min}} \le \boldsymbol{\delta} \le \boldsymbol{\delta_{max}}$$

Where, "$\boldsymbol{V_{min}}$" & "$\boldsymbol{V_{max}}$" are the lower and upper limits of the magnitude, "$\boldsymbol{V}$" is the voltage magnitude of the system. "$\boldsymbol{\delta_{min}}$" & "$\boldsymbol{\delta_{max}}$ are the lower and upper limits of the phase, "$\boldsymbol{\delta}$" is the voltage phase of the system.

2. **Generator Constraints:**

$$\boldsymbol{P_{min}} \le \boldsymbol{P} \le \boldsymbol{P_{max}}$$

$$\boldsymbol{Q_{min}} \le \boldsymbol{Q} \le \boldsymbol{Q_{max}}$$

Where, "$\boldsymbol{P_{min}}$" & "$\boldsymbol{P_{max}}$" are the lower and upper limits of the active power generation at the generator side, "$\boldsymbol{P}$" is the active power generated of the system. "$\boldsymbol{Q_{min}}$" & "$\boldsymbol{Q_{max}}$are the lower and upper limits of the reactive power at the bus of the system, "$\boldsymbol{Q}$" is the reactive power at the bus of the system

The loading (in KVA) of the generator should not exceed the prescribed value.

3. **Spare Capacity Constraints:**

These constraints are essential to meet a forced outage of one or more alternators within the system and an unexpected load which may be applied on the system. The total power generation should be such that it should meet load demand, various losses and minimum spare capacity, i.e. G ≥ Pp + Pso

4. **Transmission Line Constraints:**

The flow of active power and reactive power in the transmission line is limited by the thermal capability of the circuit generally expressed as

Cp ≤ Cpmax ;

Cpmax is the maximum loading capacity of the Pth line.

5. **Transformer Tapping Constraints:**

For an auto-transformer, the minimum tap settings is zero and maximum can be 1, i.e.

0 ≤ t ≤ 1.0 .

Similarly, in case of a two winding transformer, if there are tappings on the secondary side, we have

0 ≤ t ≤ n ; n is known as the transformation ratio.

Equality Constraints:

These constraints focus on active and reactive power equations only.

3. Power Electronic Devices

Generally there are two sources of reactive power (RP) i.e. capacitors and inductors/reactors. Capacitors store electrical energy in the form of electric fields hence generates RP. Reactors store electrical energy in the form of magnetic fields and therefore absorb reactive power [22].There are two types of RP resources; static resources and dynamic resources

3.1Static /Passive Resources

These are resources that have fixed reactive power output that cannot be changed instantaneously. The reactive power generated/absorbed by a capacitor/reactor,

$$Q = \frac{V^2}{X}$$

Where, V is the bus voltage and X the reactance; X=ωL for inductor of inductance, L (in henries) and X=1/ (ωC) for a capacitor (in farads).Its generation is fixed and proportional to X, but the voltage of its connecting bus cannot be directly controlled. In other words, a bus with a connected capacitor/reactor is, in fact, a PQ bus. [1]

Shunt compensation is more or less like load compensation with all the advantages associated with it. There's need to point out here that shunt capacitors/inductors cannot be distributed uniformly along the line. These are normally connected at the end of the line and/or at midpoint of the line. Shunt capacitors raise the load power factor (pf) which greatly increases the power transmitted over the line as it is not required to carry the reactive power. The power transmission can be increased by using shunt compensation but for fulfilling the requirements it would required large capacitor bank,which imposed the limitation and would become impractical. So transmission capacity can be improved by adopting series compensation or by higher transmission voltages.

When switched capacitors are employed for compensation, these should be disconnected immediately under light load conditions to avoid excessive voltage rise and ferro-resonance in presence of transformer [46],this is because charging current should be kept below the rated full-load current of the line. The charging current is by B_c |V|, where B_c is the total capacitive susceptance of the line and |V| is the rated voltage to neutral. If the total inductive susceptance is B_r due to several inductors connected (shunt compensation) from line to neutral at appropriate places along the line, then the charging current would be:-

$$I_{chg} = B_c - B_r * |V| = B_c|V| \; 1 - \frac{B_r}{B_c}$$

Where $1 - \frac{B_r}{B_c}$ is the reduction factor for charging current while $\frac{B_r}{B_c}$ is the shuntcompensation factor. This implies that the receiving end voltage is reduced therefore reducing Ferranti effect as the load decreases.

3.2 Dynamic / Active resources

These are resources whose reactive power capability can be changed instantly, and its value is dictated by the system conditions. These have the advantage of voltage control and load stabilization thereby ensuring generators operate at near unity power factor and minimizing blackouts.

Static Var Compensator (SVC): This is an automated impedance matching device that comprises capacitor bank fixed or switched (controlled) or fixed capacitor bank and switched reactor bank in parallel. These compensators draw reactive power (leading or lagging) from the line there by regulating voltage, improving both steady-state and transient stability and reducing voltage and current unbalances. They also have the ability to damp out sub-harmonic oscillations in HVDC application. The term static in their name implies that it has no significant moving parts. The dynamic nature of the SVC lies in the use of thyristors connected in series and inverse parallel (forming thyristor valves). Voltage regulation is provided by means of a closed loop controller.

Thyristors are used as the switching devices for SVCs. They are connected in anti-parallel to switch a capacitor/ reactor unit in stepwise control. [46] When the circuitry can adjust the firing angle then the unit acts as continuously variable. Various schemes exist as discussed below.

a) Thyristor controlled reactor (TCR): A thyristor-controlled-reactor compensator consists of a combination of six pulse or twelve pulse thyristor-controlled reactors with a fixed shunt capacitor bank. The reactive power is changed by adjusting the thyristor firing angle. TCRs are characterized by continuous control, no transients and generation of harmonics. The control system consists of voltage (and current) measuring devices, a controller for error-signal conditioning, a linearizing circuit and one or more synchronizing circuits [1]

b) Thyristor switched capacitor (TSC): Consists of only thyristor switched capacitor bank split into equal number of units of equal ratings to achieve a step-wise control. They are applied as a discretely variable reactive power source, where this type of voltage support is deemed adequate. All switching takes place when the voltage across the thyristor valve is zero, thus providing almost transient free switching. Disconnection is effected by suppressing the firing to the thyristor.

c) Combined TCR and TSC: This is the optimum solution in majority of the cases. With this, continuous variable reactive power is obtained throughout the complete control range. Full control of both inductive and capacitive parts of the compensator is obtained. This is a very advantageous feature allowing optimum performance in case of a contingency e.g. line fault, load rejection etc. The circuit in Figure1 below shows a one line diagram of a typical SVC employing a TCR,TSC, harmonic filter, mechanically switched capacitor and a mechanically switched are connected to the grid through a transformer on the secondary side cool the thyristors. The harmonic filter is used to smooth the waveform by eliminating odd order harmonics [46]

Static Synchronous Compensator (STATCOM)

This is a regulating device based on voltage source converter and can act as source/sink of R Pin a power system to improve voltage stability and/or power factor. It comprises of a voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore has very little active power capability. Its reactive power however depends on the magnitude of the voltage at source converter(VSC). This means if the voltage of the VSC is lower than that at the point of connection, the STATCOM absorbs RP and vice-versa. Its response time is faster than that of the SVC mainly due to the use IGBJTs of the VSC. It also provides better reactive support for low AC voltages than SVC as its RP decreases linearly with AC voltage(by maintaining the rated current). Its disadvantage however is the fact that it exhibits more losses than the SVC and is more expensive thus limiting its use. [46, 47]

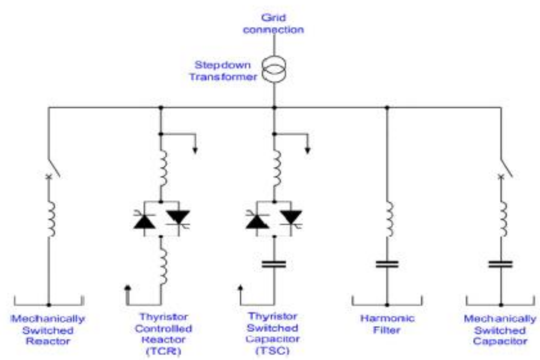

Figure 1: The line diagram of a typical SVC employing TCR, TSC and others

Synchronous Condenser

This is a synchronous motor operating at no-load and having variable excitation over a widerange. Its field can be controlled by a voltage regulator to generate RP when overexcited orabsorb RP when under-excited as needed to adjust grid voltage. The kinetic energy stored inthe rotor can help to stabilize short circuits or rapidly fluctuating loads. These have theadvantage of no generation of harmonics but have high energy losses compared to static capacitors. They are usually hydrogen cooled [46, 48].

4. Proposed Framework

Genetic algorithm is part of evolutionary algorithm (EA) and is a search algorithm based onthe process of natural selection. In genetic algorithms, the mechanics of natural selection and genetics are emulated artificially. The basic optimization procedure involves nothing more than processinghighly fit individuals in order to produce better individuals as the search progresses. Atypical genetic algorithm cycle involves four major processes, i.e.:- fitness evaluation, selection, recombination and reproduction [49].

4.1 Generation of Initial population

These are randomly generated with the population size dependent on nature of the problem but allowing entire range of possible solutions. There are two methods of choosing the initial population. One uses randomly generated solutions created by a random number generator and is preferred for problems where no prior knowledge exists. The second method is used where prior knowledge of the problem exists and therefore requirements are set that solutions have to meet to be part of the initial solution. This has the advantage of faster convergence. In this paper, we employ the initial method of randomly generating wherein no prior knowledge of the problem exists.

4.2 Solution Coding

The parameters to be optimized are usually represented in a string form since genetic operators are suitable for this type of representation. Different representation schemes might cause different performances in terms of accuracy and computation time. There are two common methods used for representation of optimization problems i.e. binary representation and real number/ integer representation. When a binary representation scheme is employed, an important issue is to decide the number of bits used to encode the parameters to be optimized. Each parameter should be encoded with the optimal number of bits covering all possible solutions in the solution space. When too few or too many bits are used the performance can be adversely affected. GA works on the encoding of a problem, not on the problem itself. This access will low more freedom and resolution for modifying the parameter features to arrive at the optimal solution [50].

4.3 Fitness Evaluation Function

This acts as an interface between the GA and the optimization problem. The GA assesses solutions for their quality according to the information produced by this unit and not by using direct information about their structure. The quality of a proposed solution is usually calculated depending on how well the solution performs the desired functions and satisfies the given constraints since the GA is a search technique and must be limited to exploring a reasonable region of variable space. Generally fitness is applied to maximization, however since most optimization problem involve cost then they become minimization problems. In this case therefore, the fittest individuals will have the lowest value of the associated objective function. The fitness function is normally used to transform the objective function value into a measure of relative fitness [50].

4.4 Genetic Operators

There are three main genetic operators i.e. .selection, crossover and mutation. Others such as inversion and elitism are sometimes applied. The purpose of the operators is to maintain genetic diversity and combine existing solutions into new ones.

4.4.1 Selection

This aims to reproduce more copies of individuals whose fitness values are higher than those whose fitness values are low. The selection procedure has a significant influence on driving the search towards a promising area and finding good solutions in a short time. There are mainly two selection procedures, i.e. proportional/ roulette wheel selection and ranking based selection.

The ranking-based selection is based on limiting number of trials of an individual to prevent them from generating too many offspring. This implies that each individual generates an expected number of offspring according to the rank of their fitness value. Selection pressure is the ratio of the probability that the fittest chromosome is selected as a parent to the probability that the average chromosome is selected [51]. Retaining the best individuals in a generation unchanged in the next generation, is called elitism or elitist selection. The idea is to avoid that the observed best fitted individual dies out just by selecting it for the next generation without any random experiment.

Elitism is widely used for speeding up the convergence of a GA. It should, however, be used with caution, because it can lead to premature convergence [52].

4.4.2Crossover

It is used to create new individuals (children) from two existing individuals (parents) picked from the current population by the selection operation. This involves choosing a random position in the two strings and swapping the bits that occur after this position. In one generation the crossover operation is performed on a specified percentage of the population specified by the crossover probability, Pc. The crossover rate determines the frequency of the crossover operation. It is useful at the start of optimization to discover a promising region. A low crossover frequency decreases the speed of convergence to such an area. If the frequency is too high, it leads to saturation around one solution. Crossover can also be performed in two different means: tail-tail and head-tail crossovers.

The two crossover methods can be changed during iterations: the head-tail crossover can be used in the earlier generations and then switched to tail-tail crossover in the later generations for fine tuning [53].

- One-point crossover: A crossover operator that randomly selects a crossover point within a chromosome then interchanges the two parent chromosomes at this point to produce two new offspring.
- Two-point crossover: A crossover operator that randomly selects two crossover points within a chromosome then interchanges the two parent chromosomes between these points to produce two new offspring.
- Uniform Crossover: This uses a fixed mixing ratio between two parents. Unlike one- and two-point crossover, the uniform crossover enables the parent chromosomes to contribute the gene level rather than the segment level. If the mixing ratio is 0.5, approximately half of the genes in the offspring will come from parent 1 and the other half will come from parent 2.
- Three parent crossover: In this technique, the child is derived from three parents that are randomly chosen. Each bit of first parent is checked with bit of second parent whether they are same. If same then the bit is taken for the offspring otherwise the bit from the third parent is taken for the offspring
- Arithmetic crossover: A crossover operator that linearly combines two parent chromosome vectors to produce two new offspring variables according to the following equations:
- Offspring1 = β Pmn + (1- β) Pdn
- Offspring2 = (1 – β) Pmn+ β Pdn

  Where 'β' is a random weighting in the interval [0,1] and Pmn and Pdn are the nth variables in the mother and father chromosomes respectively [51]

- Heuristic crossover: It produces a linear extrapolation of the two individuals as given by the equation below where the variables are defined as those for arithmetic crossover [52].

  Offspring = β (Pmn - Pdn) –Pmn

4.4.3 Mutation

Mutation is applied to each child individually after crossover to maintain genetic diversity from one generation of a population of algorithm chromosomes to the next. It alters one or more gene values in a chromosome from its initial state with a small probability. It involves selecting a string at random as well as a bit position at random and changing it from a 1 to a 0or vice-versa. In mutation, the solution may change entirely from the previous solution. Hence GA can come to better solution by using mutation. Mutation occurs during evolution according to a user-definable mutation probability. It is used to escape from a local minimum.

A high mutation rate introduces high diversity in the population and might cause instability. On the other hand, it is usually very difficult for a GA to find a global optimal solution with too low a mutation rate. After mutation, the new generation is complete and the procedure begins again with the fitness evaluation of the population.

4.5 Control Parameters

Important control parameters of a GA include the population size (number of individuals in the population), number of iterations, crossover rate and mutation rate. The algorithm runs iteratively until the convergence criterion is achieved.

4.6 Termination criteria

The number of generations that evolve depends on whether an acceptable solution is reached or a set number of iterations are exceeded. Various stopping criteria include:-

a) Max iterations- specify the maximum number of iterations the algorithm performs.

b) Max function evaluations -specifies the maximum number of evaluations of the objective and constraint functions the algorithm performs.

c) X tolerance specifies the termination tolerance; tolerance is a threshold which, if crossed, stops the iterations of a solver.

d) Function tolerance specifies the termination tolerance for the objective function value.

e) Nonlinear constraint tolerance specifies the tolerance for the maximum nonlinear constraint violation.

4.7 Proposed Algorithm

The problem can be solved in a sequence of steps as discussed below.

Step 1. Conduct a load-flow study on the IEEE 14-bus network.

Step 2. Read data i.e. cost coefficients, number of iterations, size of population, probabilities of crossover and mutation, minimum and maximum reactive power constraints.

Step 3. Generate the initial population of Q randomly in real code.

Step 4. Calculate the cost for the various values of Q.

Step 5. Calculate the fitness of each chromosome according to the fitness function and sort. Those that have lowest cost function are selected for the next generation. The average fitness of the population is also calculated.

Step 6. Selection based on reproduction followed by crossover with embedded mutation to create the new population for the next generation.

Step 7. The fitness of the new offspring is calculated and they are sorted in the ascending order. The lowest value of the objective function means better fitness. Therefore the fittest are selected for the next generation.

Step 8. Stop criteria. If the number of iterations reaches maximum, go to step 10. Otherwise go back to step 4.

Step 9. Run load flow to compute system losses with values of Q generated and calculates the voltage profile.

4.8 Proposed Algorithm Block Diagram

In this section, we present a block of the proposed framework based on the GA model for collective choice making incorporates non-positioned voting routines, especially the approbation voting technique, with the set hypothesis. It goes for improving gathering agreement on the cooperative choice result for analysis of the reactive power compensation devices (power electronic devices) focusing on mitigation of voltage drops.

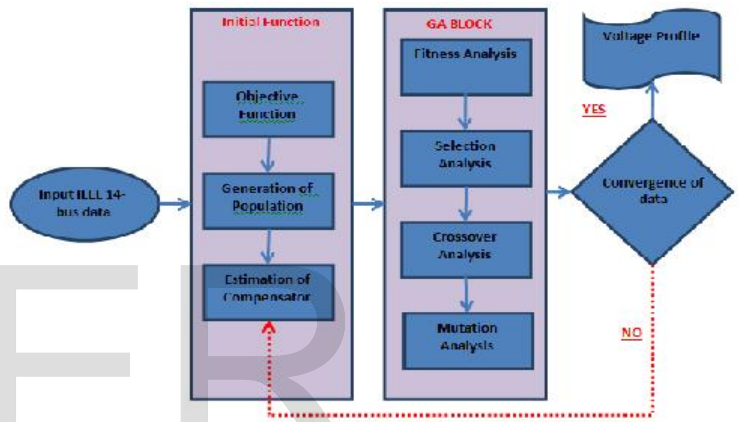

Figure 2: The block diagram of the proposed framework based on GA

5. Simulation Analysis

MATLAB packed program with functionalities MATPOWER are used to analyze the proposed system against commonly used power electronic devices for effective planning of Reactive power compensation. Simulation results have been taken for various operating conditions feeding grid under following operation conditions. AC load flow analysis was done using Matpower 6.0 to determine the system losses and bus voltages. The parameters assumed for GA analysis are presented below in Table 1

Table 1 GA Parameters

Population Size	60
No. of Units	5
Maximum Iterations	500
Crossover Probability	0.7 (70%)
Mutation Probability	0.01 (1%)

It is observed that the system losses both real and reactive reduce by about 30% and 20%respectively. This is significant enough to justify the large investment in RPCs in practical systems. Variations in voltage from their specified values also reduced thereby improving system voltage stability. The algorithm was found to converge to a global optimum after about 360 generations and with an average computational time of about 798 clock-sec. The system voltage is found to be within the limits or slightly above by 0.005 but not beyond-10% which was set as the collapse point.

MATPOWER Version 6.0b1, 01-Jun-2016 -- AC Power Flow (Newton)

Newton's method power flow converged in 3 iterations.

Converged in 0.02 seconds

System Summary

How many?		How much?	P (MW)	Q (MVAr)
Buses	14	Total Gen Capacity	772.4	-52.0 to 148.0
Generators	5	On-line Capaci '	772.4	-52.0 to 148.0
Committed Gens	5	Generation (actual)	220.7	70.1
Loads	13	Load	211.7	73.5
Fixed	13	Fixed	211.7	73.5
Dispatchable	0	Dispatchable	-0.0 of -0.0	-0.0
Shunts	1	Shunt (inj)	-0.0	21.1
Branches	20	Losses (I^2 * Z)	9.00	41.99
Transformers	3	Branch Charging (inj)	-	24.4
Inter-ties	0	Total Inter-tie Flow	0.0	0.0
Areas	1			

	Minimum	Maximum
Voltage Magnitude	1.010 p.u. @ bus 3	1.090 p.u. @ bus 8
Voltage Angle	-15.62 deg @ bus 14	0.00 deg @ bus 1
P Losses (I^2*R)	-	2.99 MW @ line 1-2
Q Losses (I^2*X)	-	9.13 MVAr @ line 1-2

Figure 3: Snap-shot of system summary

	Minimum	Maximum
Voltage Magnitude	1.010 p.u. @ bus 3	1.090 p.u. @ bus 8
Voltage Angle	-15.62 deg @ bus 14	0.00 deg @ bus 1
P Losses (I^2*R)	-	2.99 MW @ line 1-2
Q Losses (I^2*X)	-	9.13 MVAr @ line 1-2

Bus Data

Bus #	Voltage Mag(pu)	Voltage Ang(deg)	Generation P (MW)	Generation Q (MVAr)	Load P (MW)	Load Q (MVAr)
1	1.060	0.000*	180.68	-8.47	-17.43	0.00
2	1.045	-4.132	40.00	43.64	42.37	12.70
3	1.010	-7.608	0.00	0.88	23.46	19.00
4	1.014	-8.898	-	-	47.80	-3.90
5	1.017	-7.709	-	-	7.60	1.60
6	1.070	-13.589	0.00	14.33	12.22	7.50
7	1.059	-13.397	-	-	-	-
8	1.090	-15.073	0.00	19.69	19.16	0.00
9	1.053	-14.642	-	-	29.50	16.60
10	1.048	-14.741	-	-	9.00	5.80
11	1.055	-14.297	-	-	3.50	1.80
12	1.055	-14.469	-	-	6.10	1.60
13	1.050	-14.571	-	-	13.50	5.80
14	1.033	-15.615	-	-	14.90	5.00
		Total:	220.68	70.06	211.68	73.50

Figure 4: Snap-shot of IEEE 14 bus data with improvement

		Total:	220.68	70.06	211.68	73.50

Branch Data

Brnch #	From Bus	To Bus	From Bus Injection P (MW)	From Bus Injection Q (MVAr)	To Bus Injection P (MW)	To Bus Injection Q (MVAr)	Loss (I^2 * Z) P (MW)	Loss (I^2 * Z) Q (MVAr)
1	1	2	131.20	-14.20	-120.21	17.40	2.991	9.13
2	1	5	66.91	5.73	-64.72	-2.01	2.187	9.03
3	2	3	34.97	8.76	-34.39	-10.95	0.580	2.44
4	2	4	51.12	1.71	-49.72	-1.08	1.397	4.24
5	2	5	39.74	2.98	-38.91	-4.11	0.836	2.55
6	3	4	10.93	-7.18	-10.83	6.14	0.106	0.27
7	4	5	-48.24	8.19	48.55	-7.21	0.311	0.98
8	4	7	41.17	-9.18	-41.17	12.64	0.000	3.46
9	4	9	19.82	-0.18	-19.82	2.17	0.000	2.00
10	5	6	47.47	11.72	-47.47	-6.67	0.000	5.06
11	6	11	8.78	3.69	-8.71	-3.54	0.075	0.16
12	6	12	7.98	2.49	-7.90	-2.34	0.075	0.16
13	6	13	18.49	7.30	-18.26	-6.85	0.228	0.45
14	7	8	19.16	-18.57	-19.16	19.69	0.000	1.12
15	7	9	22.01	5.93	-22.01	-5.42	0.000	0.51
16	9	10	3.82	4.14	-3.81	-4.12	0.009	0.02
17	9	14	8.51	3.57	-8.41	-3.36	0.098	0.21
18	10	11	-5.19	-1.60	5.21	1.74	0.022	0.05
19	12	13	1.80	0.74	-1.79	-0.73	0.008	0.01
20	13	14	6.56	1.78	-6.49	-1.64	0.072	0.15
						Total:	8.995	41.99

Figure 5: Snap shot of individual bus information

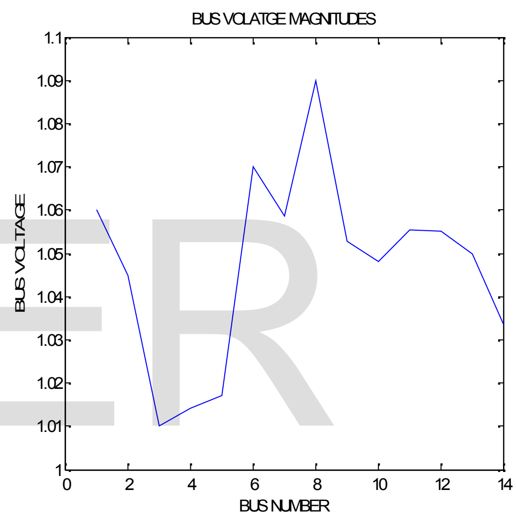

Figure 6: Bus voltage magnitudes

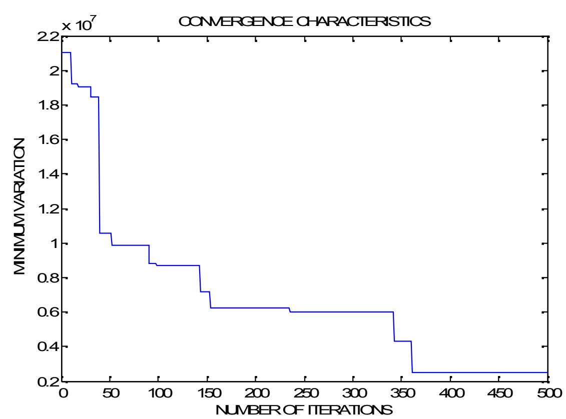

Figure 7: Convergence Characteristics

6. Conclusion

The prime focus of this paper was to understand and analyze the impact of Reactive Power Planning in the field of power systems. We proposed an approach that could identify the requirement and volume of the reactive power resources at various locations subject to pre and post fault conditions to stabilize the operating conditions to normal. From the detail analysis and study it has been evident that the dynamic nature of power electronic devices improves the faulty conditions significantly and convergence of the entire system response is relatively quick. In practical power network structure is primary factor for righteous reactive power estimation function at any stage as there is significant lost and cost attached to power system network. We employ various factors such as selection, crossover and mutation with the aim of improving fitness of subsequent generations for survival.

The power system being a practical system has several constraints such as capacity limits of the resources, system voltage limits etc. The IEEE 14-bus network was used as the test network and the code developed using MATLAB for analyzing the impact of power electronic devices on the RPP problem. Results obtained show a reduction in real and reactive losses and improvement in the voltage profile i.e. reduced by about 30% and 20%respectively. This is significant enough to justify the large investment in RPCs in practical systems. Variations in voltage from their specified values also reduced thereby improving system voltage stability. The algorithm was found to converge to a global optimum after about 360 generations and with an average computational time of about 798 clock-sec. The system voltage is found to be within the limits or slightly above by 0.005 but not beyond-10% which was set as the collapse point.

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